ARMY RESEARCH LABORATORY

Ballistic Evaluation of 7085 Aluminum

by Denver Gallardy

ARL-TR-5952 **March 2012**

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Army Research Laboratory
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Denver Gallardy
Weapons and Materials Research Directorate, ARL

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14. ABSTRACT
The U.S. Army Research Laboratory (ARL) evaluated the ballistic performance of two tempers of aluminum alloy (AA) 7085 produced by Alcoa. The tempers included a high-strength variant, 7085-T7E01, for utilization as an appliqué against direct-fire threats and a lower strength, higher ductility variant, 7085-T7E02, for underbody blast protection kits. Ballistic evaluation was performed using armor-piercing and fragment-simulating projectiles to determine the V_{50} ballistic protection limit (V_{50}) for various thicknesses of each temper. The V_{50} was then compared to other ballistic-grade aluminum alloys, namely AA7039 and AA2139. The results of these tests were used to derive the acceptance tables included in the new military specification, MIL-DTL-32375(MR), created for AA7085.

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Contents

List of Figures

List of Tables

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1. Introduction

Aluminum alloy (AA) 7085-T7XXX is an aerospace grade aluminum alloy currently available in large volume production for the aircraft industry. The alloy was investigated for armor utilization by Alcoa. Two tempers were developed, a high-strength variant, 7085-T7E01, for utilization as an appliqué against direct-fire threats and a lower strength, higher ductility variant, 7085-T7E02, for underbody blast protection kits. The U.S. Army Research Laboratory (ARL) initially requested to test this alloy in late 2008; the first few thicknesses of plates were tested by Gooch (*1*) in the first half of 2009. For current force operations, high-performance blast resistant alloys have been sought, and AA7085-T7E02 was the material selected by Oshkosh for the heavy expanded mobility tactical truck (HEMTT) A4 M984A4 Wrecker underbody protection kit. The development of a military specification for 7085 was requested by the product manager of heavy tactical vehicles, and work was initiated by ARL to develop the specification, which was published in September 2011. To date, over 450 HEMTT A4 M984A4 Wrecker underbody protection kits have been manufactured and fielded.

Several thicknesses from both temper variants were provided to ARL by Alcoa. Table 1 is a summary matrix of the tested thicknesses for both tempers. Additionally, the required chemistries for AA7085, as well as other common aluminum armor alloys, are provided in table 2. It should be noted that the T7E01 and T7E02 temper designations are temporary experimental designations. These tempers are being registered with the Aluminum Association, and official tempers conforming to Aluminum Association standards will be assigned to each variant (*2*).

Table 1. Test matrix for aluminum alloy 7085-T7E01 and 7085-T7E02.

Nominal Plate Gage	0.30-cal. APM2 30° Obliquity		0.30-cal. APM2 0° Obliquity		0.50-cal. APM2 0° Obliquity		14.5-mm BS41 0° Obliquity		0.50-cal. FSP 0° Obliquity		20-mm FSP 0° Obliquity	
(mm)	E01	E02	E01	E02	E01	E02	E01	E02	E01	E02	E01	E02
12.70	X	X	—	—	—	—	—	—	—	—	—	—
19.05	X	X	X	X	—	—	—	—	X	X	—	—
25.40	—	—	X	X			—	—	X	X	X	X
38.10	—	—	X	X	X	X	—	—	—	—	X	X
40.64	—	—	X	X	—	—	—	—	—	—	—	—
50.80	—	—	—	—	X	X	—	—	—	—	—	—
57.15	—	—	—	—	X	X	—	—	—	—	—	—
63.50	—	—	—	—	X	X	X	—	—	—	—	—
76.20	—	—	—	—	X	X	X	—	—	—	—	—

Note: FSP = fragment-simulating projectile.

Table 2. Chemistry of AAs, weight-percent ranges (*3*).

Element	7085	7039	5083	2519	2139	2195
Copper	1.3–2.0	0.10 max	0.10 max	5.30–6.40	4.5–5.5	3.70–4.30
Iron	0.08 max	0.40 max	0.40 max	0.30 max[a]	0.15 max	0.15 max
Lithium	—	—	—	—	—	0.80–1.20
Chromium	0.04 max	0.15–0.25	0.05–0.25	—	0.05 max	—
Manganese	0.04 max	0.10–0.40	0.40–1.0	0.10–0.50	0.20–0.60	0.25 max
Magnesium	1.2–1.8	2.30–3.30	4.0–4.90	0.05–0.40	0.20–0.80	0.25–0.80
Silicon	0.06 max	0.30 max	0.40 max	0.25 max[a]	0.10 max	0.12 max
Titanium	0.06 max	0.10 max	0.15 max	0.02–0.10	0.15 max	0.10 max
Zinc	7.0–8.0	3.50–4.50	0.25 max	0.10 max	0.25 max	0.25 max
Zirconium	0.08–0.15	—	—	0.10–0.25	—	0.08–0.16
Silver	—	—	—	—	0.15–0.60	0.25–0.60
Others (each)	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max
Others (total)	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max
Aluminum	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

[a]The total weight percentage of the combination of silicon and iron cannot exceed 0.40%.

2. Experimental Procedure

The V_{50} is defined as the impact velocity at which the projectile is as equally likely to penetrate the target as it is to arrest. A 0.51-mm (0.020-in) 2024 T3 aluminum witness plate is positioned 152 mm (6 in) behind the target in order to determine the outcome of each shot. An impact is regarded as a complete penetration (CP), or loss, if the projectile or a resulting target fragment from impact creates a hole in the witness plate through which light can be observed. If an impact does not result in a CP, it is considered a partial penetration (PP), or win. In order to keep results as consistent as possible, only shots conforming to the following conditions were used to determine the V_{50}. The projectile must be unyawed, <2° of total yaw for armor-piercing (AP) rounds and <5° of total yaw for FSPs, and impact the target at least 2 projectile diameters from any previous impact, damage, or edge of the target. Total yaw is defined as the vector sum of the projectile's pitch and yaw. The V_{50} is calculated by the arithmetic mean of an equal number of CPs and PPs within an 18-m/s (60-ft/s) spread for a 2 + 2 V_{50}, a 27 m/s (90 ft/s) spread for a 3 + 3 V_{50}, and as small of a spread as attainable for a 5 + 5 V_{50} (*4*).

Projectile velocities for the determination of the V_{50} were measured using one of two methods, as shown in figure 1. The first method is an orthogonal flash x-ray system as described in detail by Grabarek and Herr (*5*), which also measures pitch and yaw. The second method uses three infrared (IR) screens and a chronograph. The velocity is calculated using the first and third screen, with the middle screen used to check for bad readings. The flash x-ray method was used in situations with projectiles that historically exhibit excessive yaw or if space did not allow

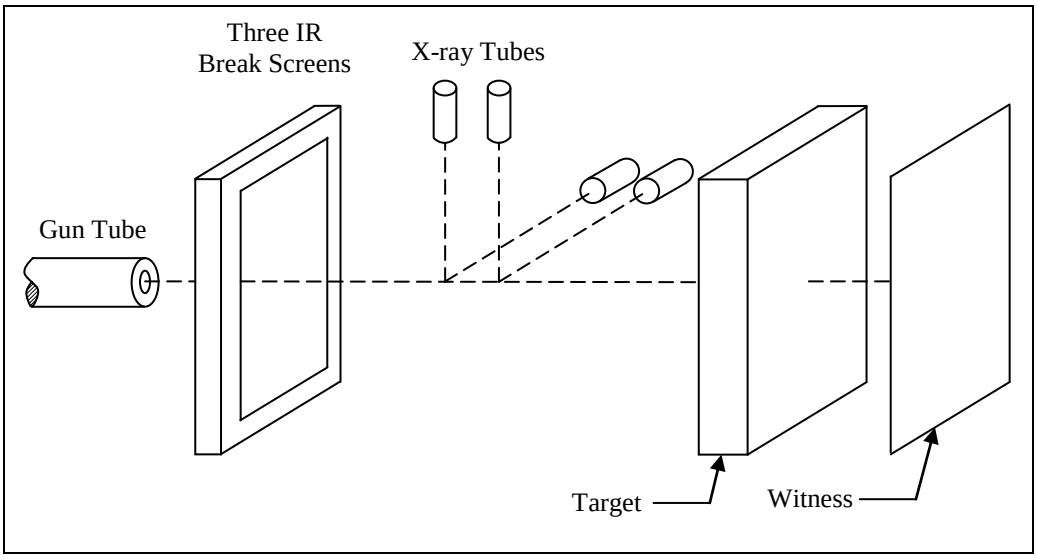

Figure 1. Typical test setup.

the use of IR break screens. When the IR break screens and chronograph were used, the projectile velocity was corrected to the target impact location using a correction factor based on an initial flash x-ray reading at the impact location. The correction was made using equations 1 and 2 in lieu of utilizing air drag factors.

$$\frac{(\text{x-ray velocity})}{(\text{chronograph velocity})} = (\text{correction factor}) . \quad (1)$$

$$(\text{correction factor}) \times (\text{chronograph velocity}) = (\text{corrected velocity}) . \quad (2)$$

3. Test Projectiles

3.1 Armor-Piercing Projectiles

The U.S. 0.30-cal. APM2, 0.50-cal. APM2, and the soviet 14.5-mm BS41 are the three AP projectiles that were used in this study. These projectiles are shown in figure 2. The APM2 projectiles have hardened steel cores with a hardness of Rockwell C61-63, whereas the BS41 has a tungsten carbide core. The physical characteristic of these projectiles are listed in table 3.

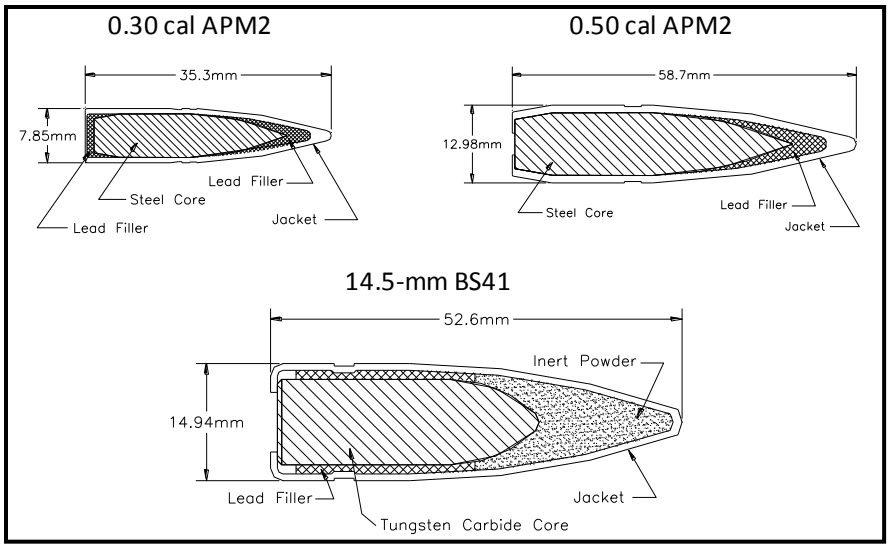

Figure 2. AP projectiles.

Table 3. AP projectile physical characteristics (*6*).

Projectile Type	Projectile			Core		
	Length (mm)	Diameter (mm)	Weight (g)	Length (mm)	Diameter (mm)	Weight (g)
0.30-cal. APM2	35.3	7.85	10.8	27.4	6.2	5.3
0.50-cal. APM2	58.7	12.98	45.9	47.5	10.9	25.9
14.5-mm BS41	52.6	14.94	63.2	32.3	10.9	37.9

3.2 Fragment-Simulating Projectiles

FSPs (figure 3) are a family of projectiles that are flat-nosed, right circular cylinders manufactured to MIL-DTL-46593B (MR) (*7*). These projectiles are used in material evaluations and acceptance testing to simulate performance against fragments produced from improvised explosive devices and artillery. Both 0.50-cal. and 20-mm FSPs were used for the evaluation of AA7085.

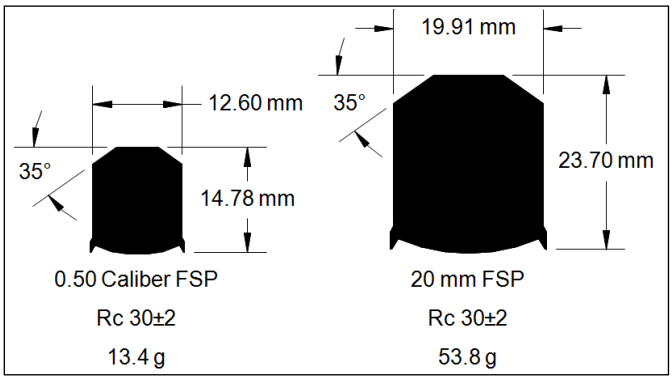

Figure 3. FSPs.

4. Results and Analysis

The test results, including the V_{50} and its standard deviation (σ), are summarized in table 4. The individual shot records are additionally provided in appendices A and B.

Table 4. V_{50} ballistic limits for AA7085-T7E01 and AA7085-T7E02.

Plate Gauge (mm)	Brinell (3000-kg Load)	0.30-cal. APM2 30° Obliquity		0.30-cal. APM2 0° Obliquity		0.50-cal. APM2 0° Obliquity		14.5-mm BS41 0° Obliquity		0.50-cal. FSP 0° Obliquity		20-mm FSP 0° Obliquity	
		V_{50} (m/s)	σ	V_{50} (m/s)	σ	V_{50} (m/s)	σ	V_{50} (m/s)	σ	V_{50} (m/s)	σ	V_{50} (m/s)	σ
7085-T7E01													
12.60	183	511	8	—	—	—	—	—	—	—	—	—	—
18.57	179	668	8	598	4	—	—	—	—	631	9	—	—
25.35	170	—	—			—	—	—	—	1026	8	461	6
25.40	170	—	—	772	8	—	—	—	—	1061	13	448	12
37.95	179	—	—	908	8	665	4	—	—	—	—	835	6
40.51[a]	174	—	—	938	8	—	—	—	—	—	—	—	—
52.83[a]	174	—	—	—	—	809	10	—	—	—	—	—	—
56.52	166	—	—	—	—	853	9	—	—	—	—	—	—
63.35	174	—	—	—	—	907	9	838	5	—	—	—	—
74.00	170	—	—	—	—	990[b]	—	937	5	—	—	—	—
7085-T7E02													
12.62	149	481	8	—	—	—	—	—	—	—	—	—	—
18.52	153	614	7	567	10	—	—	—	—	573	8	—	—
25.40	149	—	—	—	—	—	—	—	—	982	5	457	8
25.45	149	—	—	664	11	—	—	—	—	957	7	430	9
37.97	143	—	—	842	6	635	8	—	—	—	—	806	8
40.49[a]	149	—	—	872	8	—	—	—	—	—	—	—	—
52.76[a]	146	—	—	—	—	753	8	—	—	—	—	—	—
56.31	146	—	—	—	—	792	7	—	—	—	—	—	—
63.60	146	—	—	—	—	847	8	—	—	—	—	—	—

[a]Data from Gooch (*1*).
[b]Partial penetration at maximum projectile velocity.

The results of the ballistic evaluations for both tempers are compared against the acceptance curves of AA7039 and AA2139. MIL-DTL-46063H (*8*) is the current 7xxx series aluminum armor specification and covers AA7039. This specification was used as the baseline for 7xxx series aluminums to determine any performance benefits for AA7085. The other specification used for comparison is MIL-DTL-32341 (MR) (*9*), which is the recently released unweldable 2xxx series specification and includes AA2139 and AA2195. These alloys can be considered state-of-the art in terms of ballistic performance, and the ballistic acceptance curves for AA2139 were used for comparison. Figures 4–9 show the AA7085 test data collected by ARL as compared to the other specifications. The data displayed is the V_{50} as a function of the plate thickness. To allow a fair comparison against the existing specifications, a line depicting the

V_{50} -2σ was plotted against the acceptance specs. This line represents a V_{02} rather than a V_{50}. To ensure successful protection at a given thickness, the lower band of the 2σ distribution (V_{02} line) is used to define minimum acceptable performance. A V_{50} falling below this line is considered unacceptable.

As can be observed in the plots (figures 4–7), the AP performance for both the AA7085-T7E01 (AP temper) and the AA7085-T7E02 (blast temper) are higher than the existing AA7039 acceptance requirements. Comparing the AP results against the AA2139 requirements shows that the AA7085-T7E01 temper has improved performance whereas the 7085-T7E02 temper falls below the AA2139 criteria. It should be noted that the AP performance of the thick 7085-T7E01 plates was significantly higher than the AA7039. Therefore, the 14.5-mm BS41 was needed to obtain the complete penetrations necessary to calculate a V_{50}. The 0.50-cal. APM2 was sufficient for the AA7085-T7E02 temper. It should also be noted that figure 4 does not contain 2139 data because the values are not currently available in the military specification.

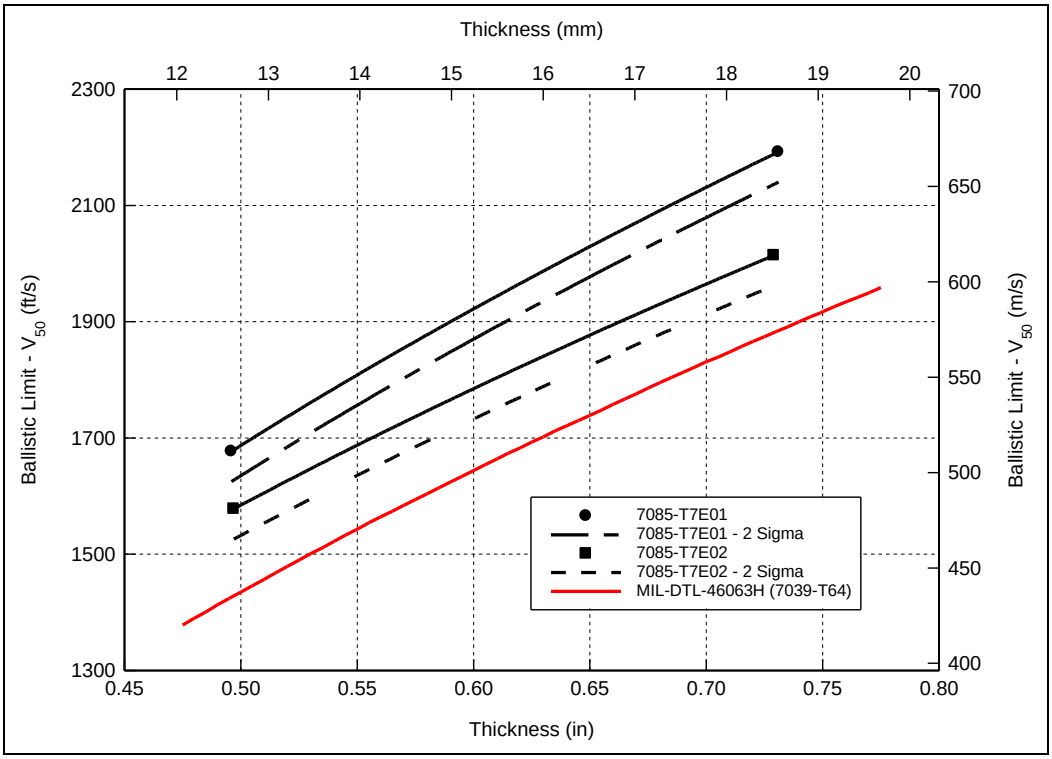

Figure 4. Ballistic limit vs. thickness of 7085-T7E01 and 7085-T7E02 compared to existing specs for the 0.30-cal. APM2 at 30° obliquity.

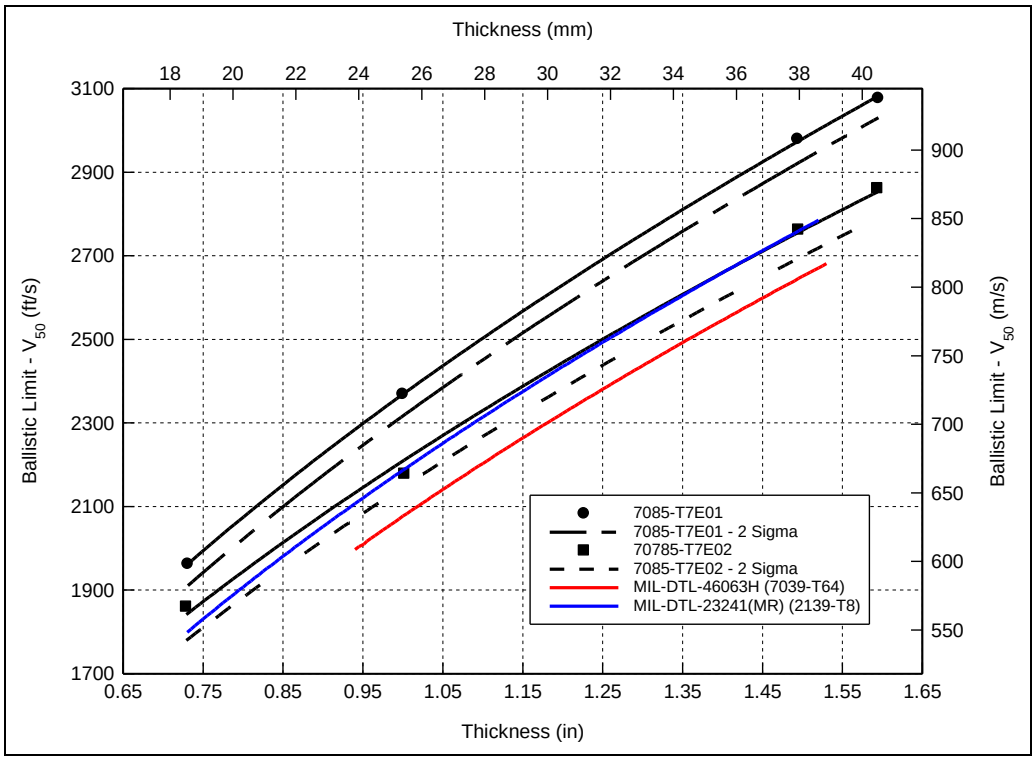

Figure 5. Ballistic limit vs. thickness of 7085-T7E01 and 7085-T7E02 compared to existing specs for the 0.30-cal. APM2 at 0° obliquity.

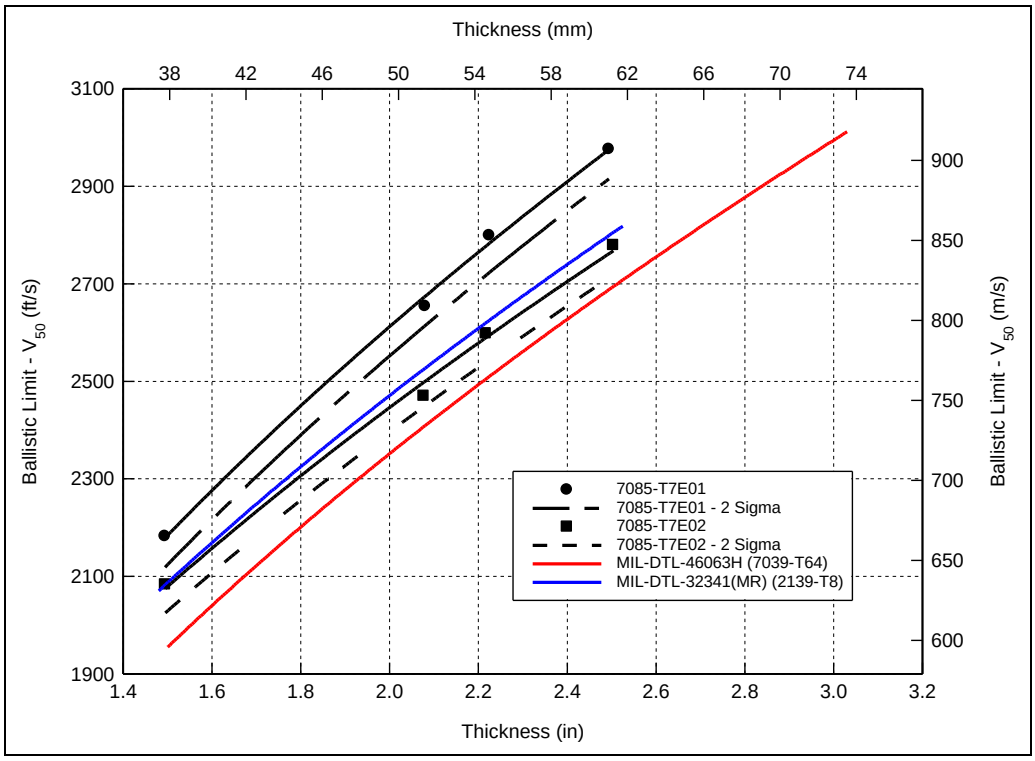

Figure 6. Ballistic limit vs. thickness of 7085-T7E01 and 7085-T7E02 compared to existing specs for the 0.50-cal. APM2 at 0° obliquity.

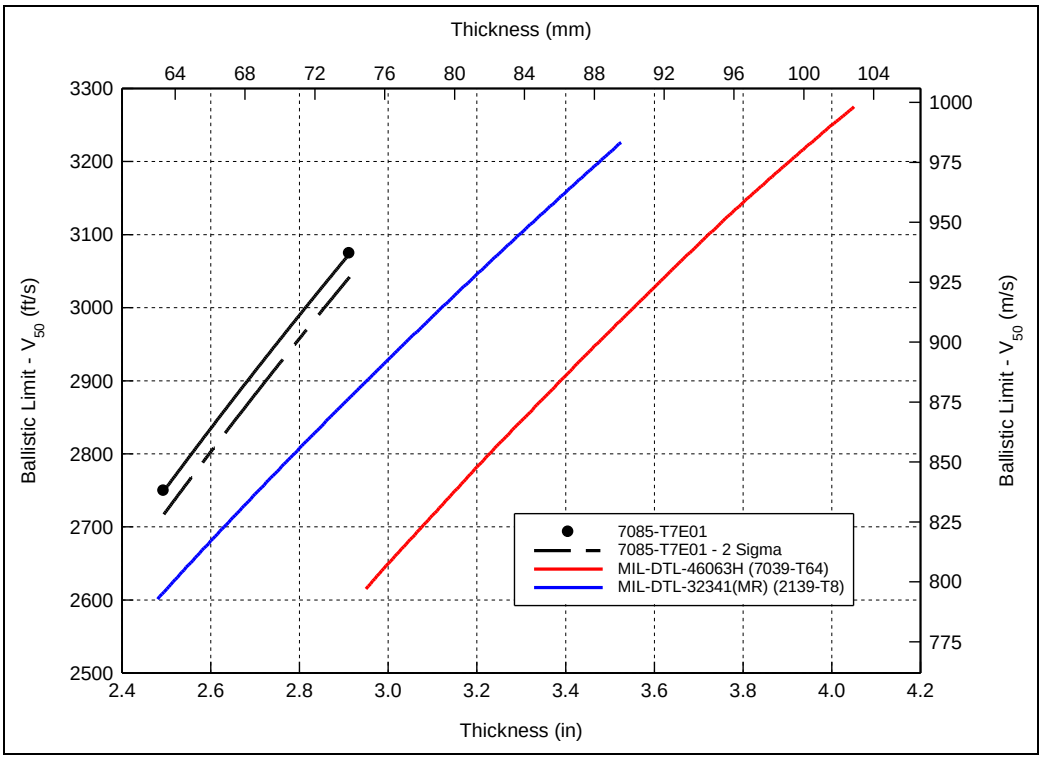

Figure 7. Ballistic limit vs. thickness of 7085-T7E01 compared to existing specs for the 14.5-mm BS41 at 0° obliquity.

Turning to the FSP performance (figures 8 and 9), it can be observed that the performance is more in line with the current armor alloys. AA7085-T7E01 displays better performance than AA7085-T7E02 against both the 0.50-cal. and 20-mm FSP in the thickness ranges called out by the military specification. The performance of AA7085-T7E02 falls in line with or just below the performance of AA7039. The performance of AA7085-T7E01 is close to, but below, the AA2139 performance against 0.50-cal. FSPs and is about halfway between the specifications for AA2139 and AA7039 against the 20-mm FSP. The backface failure is considerably different between the two tempers. AA7085-T7E01 exhibits a spalling- or discing-type failure whereas the AA7085-T7E02 shows a ductile plugging failure. A comparison of the exit holes can be seen in figure 10.

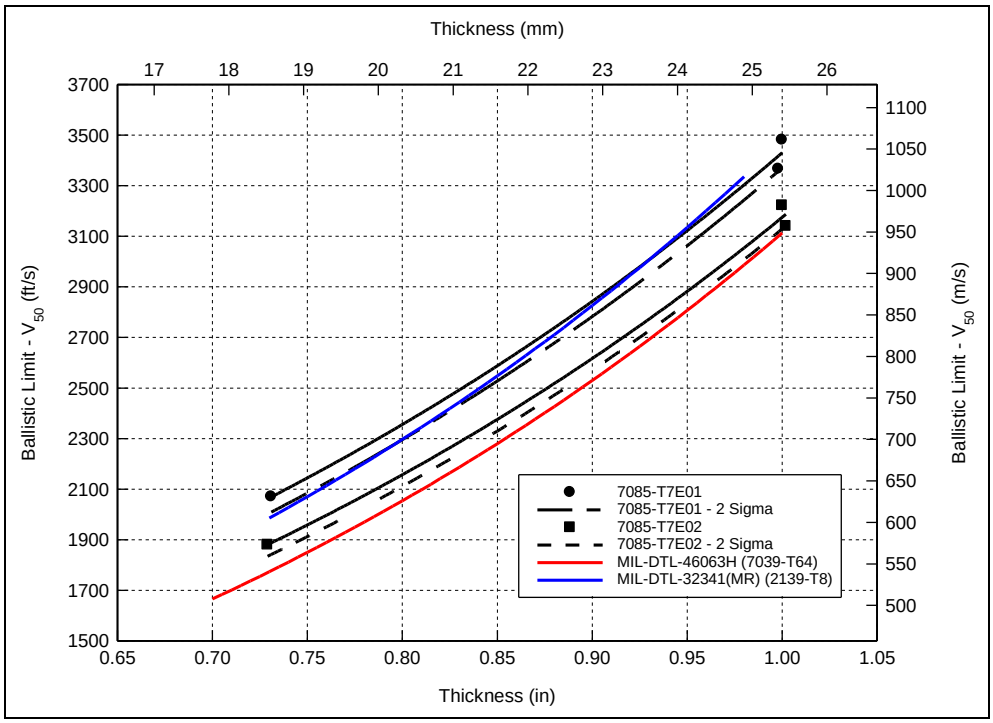

Figure 8. Ballistic limit vs. thickness of 7085-T7E01 and 7085-T7E02 compared to existing specs for the 0.50-cal. FSP at 0° obliquity.

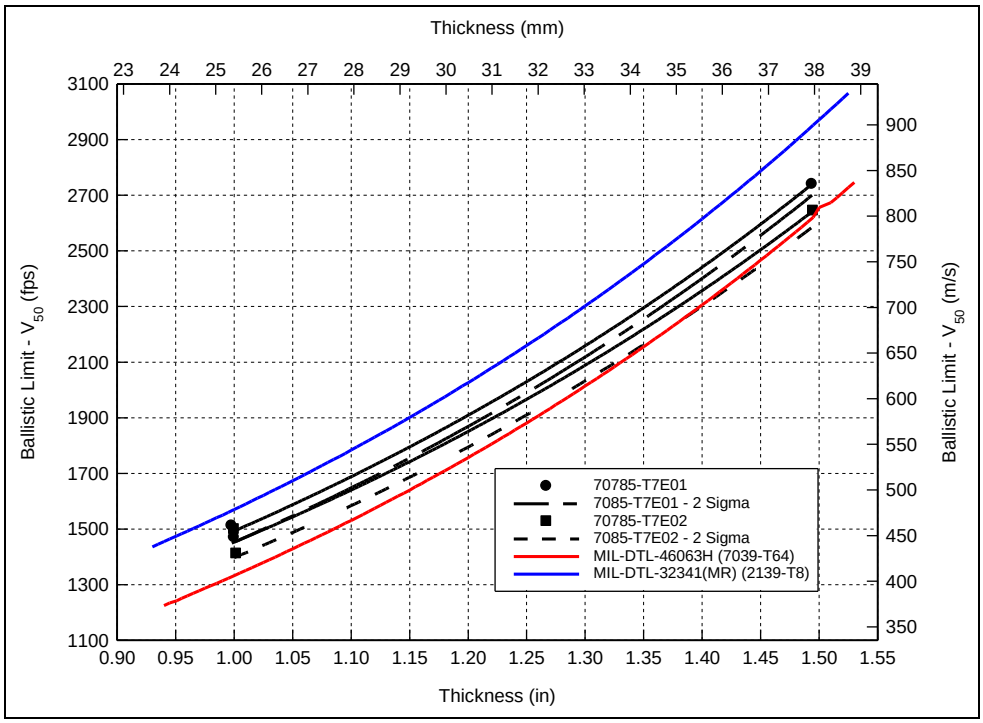

Figure 9. Ballistic limit vs. thickness of 7085-T7E01 and 7085-T7E02 compared to existing specs for the 20-mm FSP at 0° obliquity.

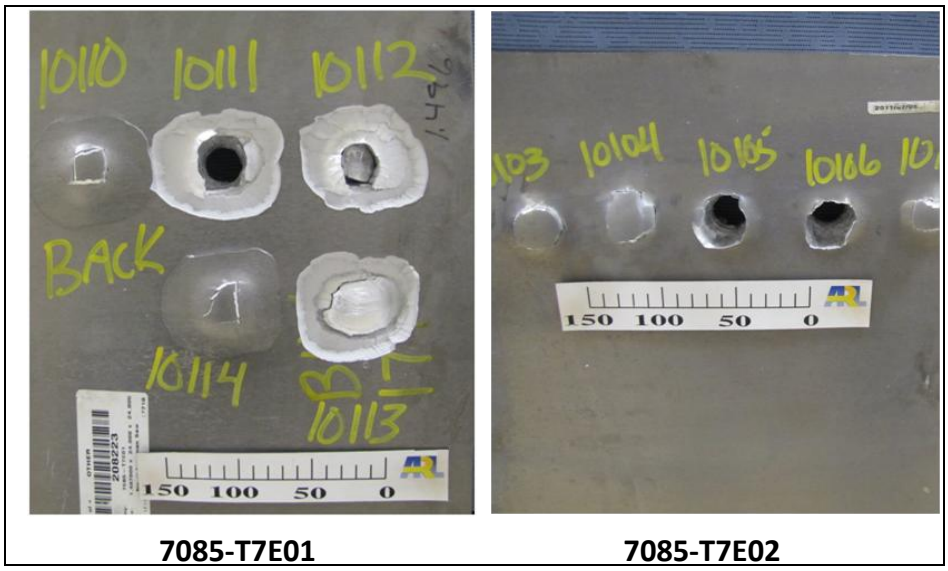

Figure 10. A comparison of 20-mm FSP exit holes.

The data collected by ARL, as well as data collected by the U.S. Army Aberdeen Test Center (*10*) found in appendix C, was then used to generate acceptance tables for MIL-DTL-32375(MR) (*11*). The acceptance velocities were calculated by fitting the V_{50} data minus two standard deviations with equations 3 and 4 for AP and FSP projectiles, respectively (*12*).

$$V_A = 1000\sqrt{a + bt} \ . \tag{3}$$

$$V_A = 1000e^{a+bt} \ . \tag{4}$$

In equations 3 and 4, V_A is the acceptance velocity, t is the actual thickness of the plate, and a and b are constants of regression. Table 5 lists the constants of regression and the Pearson's R correlation coefficient for each projectile. The calculated acceptance curves for each temper, as well as the V_{50} data points used in the calculation, are plotted in figures 11–16. The ballistic tables corresponding to the acceptance curves can be found in MIL-DTL-32375 (MR).

Table 5. Constants of regression for the acceptance curves for AA7085.

Projectile Type	7085-T7E01			7085-T7E02		
	a	**b**	**R**	**a**	**b**	**R**
0.30-cal. AP, M2 at 30°	–1.22219	7.82805	0.9985	–0.63968	5.96279	0.9830
0.30-cal. AP, M2 at 0°	–1.00510	6.38362	0.9996	–0.73629	5.38098	0.9980
0.50-cal. AP, M2 at 0°	–1.15025	3.84480	0.9975	–1.50631	3.59186	0.9948
14.5-mm BS41 at 0°	–3.72241	4.45249	1	NA	NA	NA
0.50-cal. FSP at 0°	–0.87107	2.08372	0.9955	–0.79585	1.93870	0.9982
20-mm FSP at 0°	–0.92069	1.28106	0.9983	–0.96678	1.28373	0.9962

Note: NA = not applicable.

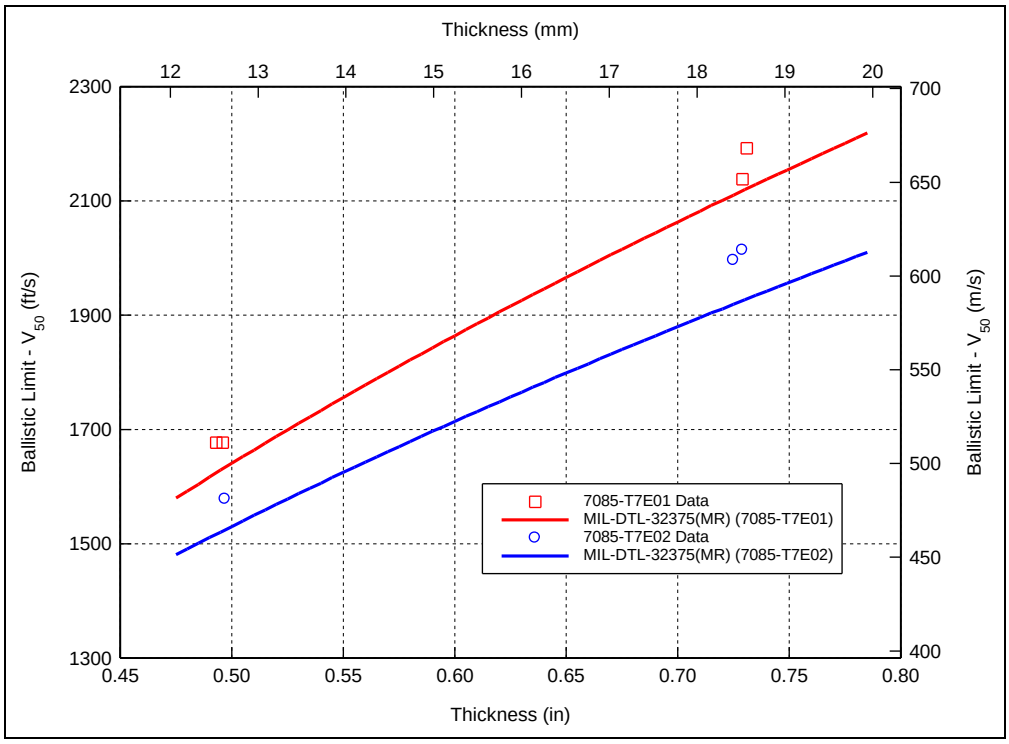

Figure 11. Acceptance curves for 7085-T7E01 and 7085-T7E02 for the 0.30-cal. APM2 at 30° obliquity.

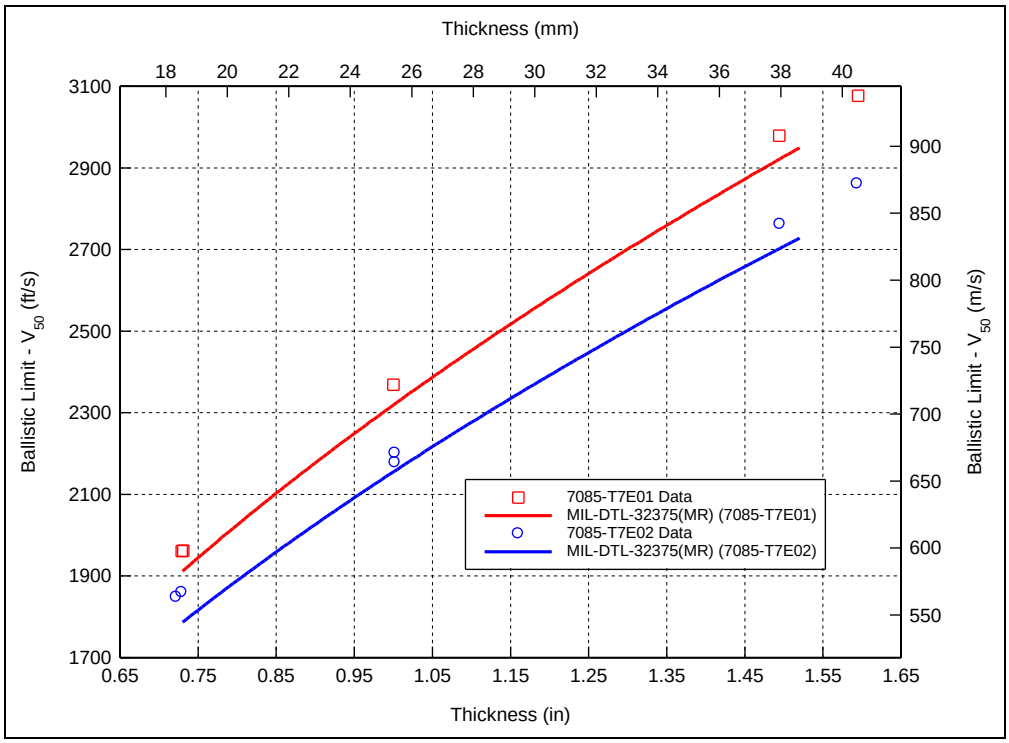

Figure 12. Acceptance curves for 7085-T7E01 and 7085-T7E02 for the 0.30-cal. APM2 at 0° obliquity.

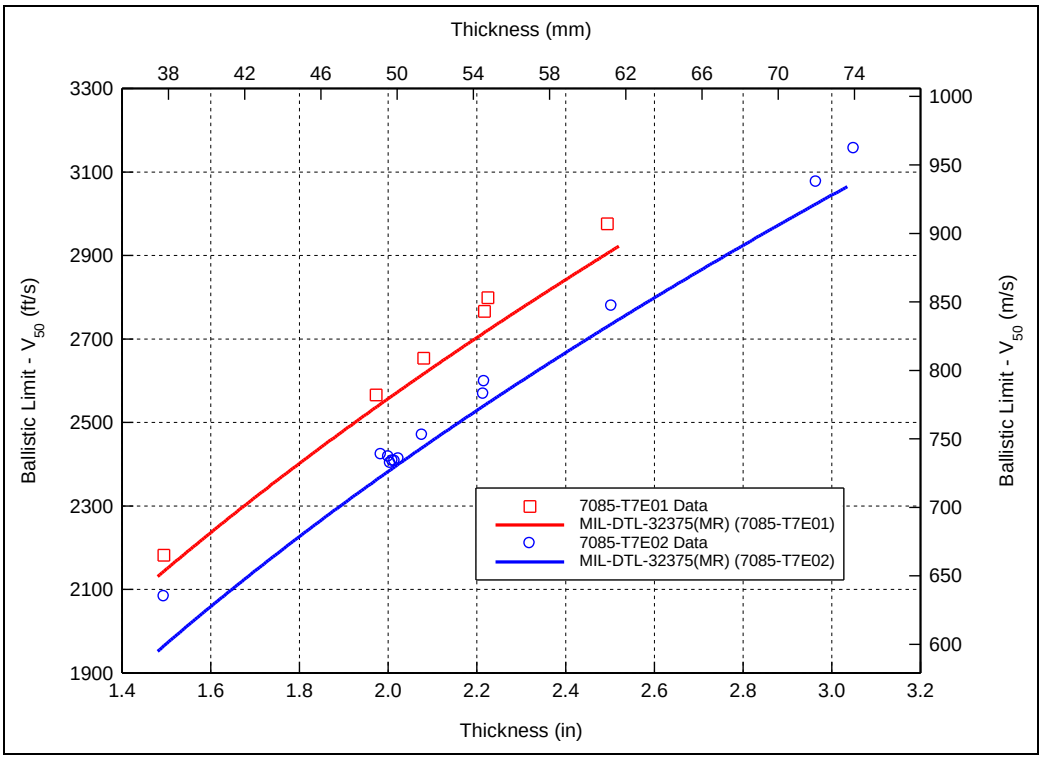

Figure 13. Acceptance curves for 7085-T7E01 and 7085-T7E02 for the 0.50-cal. APM2 at 0° obliquity.

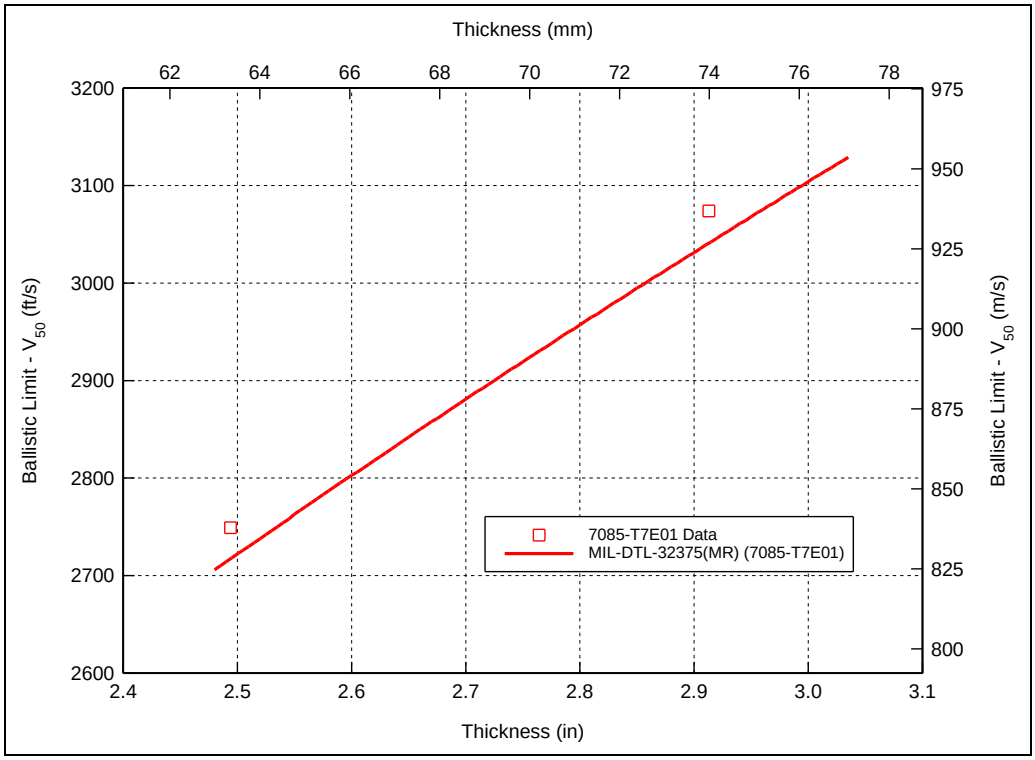

Figure 14. Acceptance curve for 7085-T7E01 for the 14.5-mm BS41 at 0° obliquity.

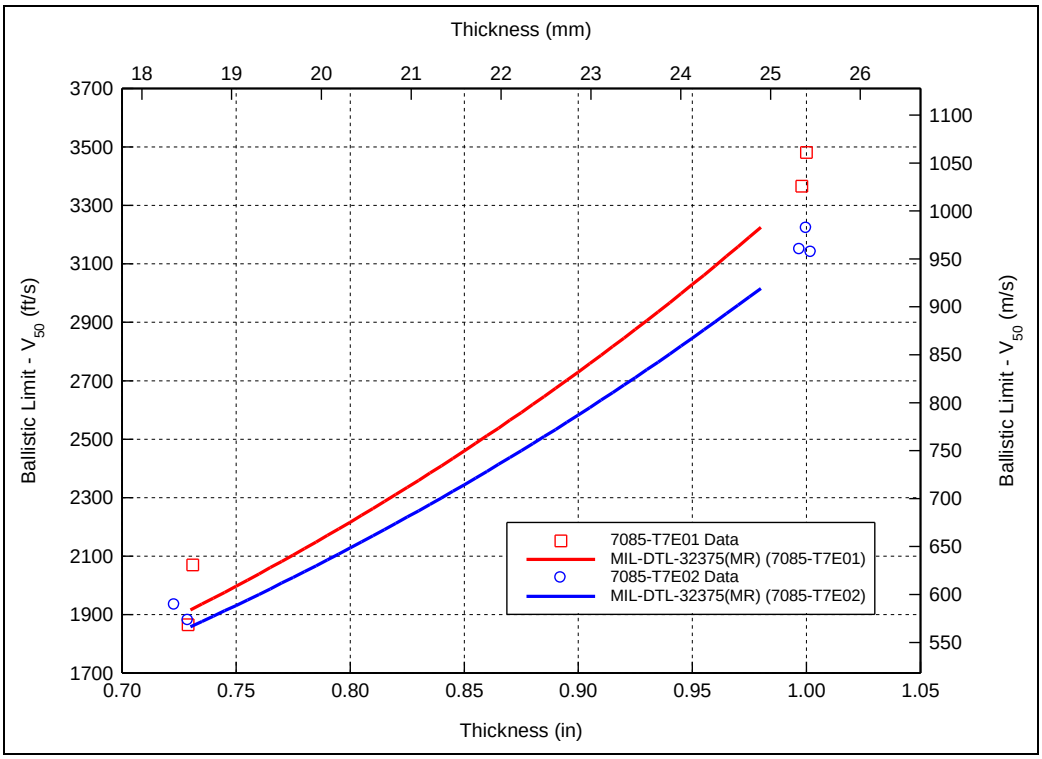

Figure 15. Acceptance curves for 7085-T7E01 and 7085-T7E02 for the 0.50-cal. FSP at 0° obliquity.

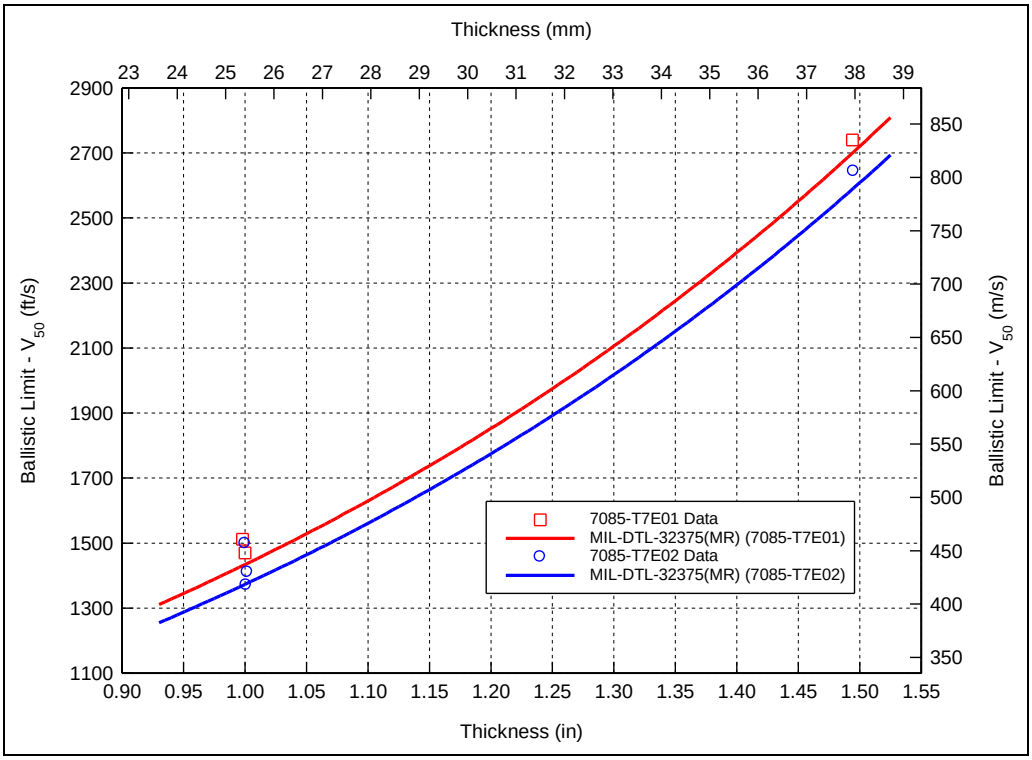

Figure 16. Acceptance curves for 7085-T7E01 and 7085-T7E02 for the 20-mm FSP at 0° obliquity.

5. Conclusions

A ballistic evaluation has been performed on AA7085 in both the T7E01 and T7E02 tempers. This report has compared the performance of both tempers against existing mil spec aluminum armor material, namely AA7039 and AA2139. Both tempers of 7085 performed better than the AA7039 specification against AP projectiles. Additionally, 7085-T7E01 performed better than the AA2139 specification against the AP projectiles. The FSP performance of 7085-T7E01 fell between the specifications for AA7039 and AA2139, whereas 7085-T7E02 was similar to AA7039. This report has also documented the calculations used to derive the acceptance tables included in the new military specification, MIL-DTL-32375 (MR), created for AA7085.

6. References

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Appendix A. Ballistic Test Data: 7085-T7E01

This appendix appears in its original form, without editorial change.

0.30-cal APM2

Target:	**7085-T7E01**	Date:	**2/4/2011**
Plate Number:	**371-261**	Location:	**EF 106**
Thickness, mm:	**12.60**		
Hardness, BHN:	**183**		
Obliquity:	**30°**		
Projectile:	**0.30 cal APM2**		
X-ray or Chrono	**Chrono**		

V_{50}:	**511 m/s**	Number of Shots:	**6**
Std Dev:	**8 m/s**	Spread:	**22 m/s**
ZMR:	**19 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
498	**--**	**--**	**CP**	**Yes**	**10242**	
494	--	--	PP	No	10247	
520	**--**	**--**	**CP**	**Yes**	**10248**	
509	**--**	**--**	**PP**	**Yes**	**10249**	
505	**--**	**--**	**PP**	**Yes**	**10250**	
517	**--**	**--**	**PP**	**Yes**	**10251**	
514	**--**	**--**	**CP**	**Yes**	**10252**	

Target:	**7085-T7E01**	Date:	**2/8/2011**
Plate Number:	**330-172**	Location:	**EF 106**
Thickness, mm:	**18.57**		
Hardness, BHN:	**179**		
Obliquity:	**30°**		
Projectile:	**0.30 cal APM2**		
X-ray or Chrono	**Chrono**		

V_{50}:	**668 m/s**	Number of Shots:	**4**
Std Dev:	**8 m/s**	Spread:	**17 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
638	--	--	PP	No	10253	
679	**--**	**--**	**CP**	**Yes**	**10254**	
663	**--**	**--**	**PP**	**Yes**	**10255**	
667	**--**	**--**	**CP**	**Yes**	**10256**	
662	**--**	**--**	**PP**	**Yes**	**10257**	

Target:	**7085-T7E01**	Date:	**3/29/2011**
Plate Number:	**330-172**	Location:	**EF 108**
Thickness, mm:	**18.57**		
Hardness, BHN:	**179**		
Obliquity:	**0°**		
Projectile:	**0.30 cal APM2**		
X-ray or Chrono	**Chrono**		

V_{50}:	**598 m/s**	Number of Shots:	**4**
Std Dev:	**4 m/s**	Spread:	**7 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
662	--	--	CP	No	9803	
629	--	--	CP	No	9804	
513	--	--	PP	No	9805	
555	--	--	PP	No	9806	
602	**--**	**--**	**CP**	**Yes**	**9807**	
577	--	--	PP	No	9808	
595	**--**	**--**	**PP**	**Yes**	**9809**	
613	--	--	CP	No	9810	
595	**--**	**--**	**PP**	**Yes**	**9811**	
601	**--**	**--**	**CP**	**Yes**	**9812**	

Target:	**7085-T7E01**	Date:	**2/10/2011**
Plate Number:	**307-433**	Location:	**EF 106**
Thickness, mm:	**25.4**		
Hardness, BHN:	**170**		
Obliquity:	**0°**		
Projectile:	**0.30 cal APM2**		
X-ray or Chrono	**Chrono**		

V_{50}:	**722 m/s**	Number of Shots:	**4**
Std Dev:	**8 m/s**	Spread:	**17 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
705	--	--	PP	No	10271	
712	**--**	**--**	**PP**	**Yes**	**10272**	
745	--	--	CP	No	10273	
734	--	--	CP	No	10274	
727	**--**	**--**	**CP**	**Yes**	**10275**	
718	**--**	**--**	**PP**	**Yes**	**10276**	
729	**--**	**--**	**CP**	**Yes**	**10277**	

Target:	**7085-T7E01**	Date:	**7/22/2011**
Plate Number:	**208-233**	Location:	**EF 106**
Thickness, mm:	**37.95**		
Hardness, BHN:	**179**		
Obliquity:	**0°**		
Projectile:	**0.30 cal APM2**		
X-ray or Chrono	**Chrono**		

V_{50}:	**908 m/s**	Number of Shots:	**4**
Std Dev:	**8 m/s**	Spread:	**17 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
902	**--**	**--**	**PP**	**Yes**	**10781**	
918	**--**	**--**	**CP**	**Yes**	**10782**	
896	--	--	PP	No	10783	
901	**--**	**--**	**PP**	**Yes**	**10784**	
912	**--**	**--**	**CP**	**Yes**	**10785**	

0.50-cal APM2

Target:	**7085-T7E01**	Date:	**9/22/2011**
Plate Number:	**208-233**	Location:	**EF 108**
Thickness, mm:	**37.95**		
Hardness, BHN:	**179**		
Obliquity:	**0°**		
Projectile:	**0.50 cal APM2**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**665 m/s**	Number of Shots:	**4**
Std Dev:	**4 m/s**	Spread:	**9 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
630	--	--	PP	No	10192	
698	--	--	CP	No	10193	
666	**--**	**--**	**CP**	**Yes**	**10194**	
646	--	--	PP	No	10195	
648	--	--	PP	No	10196	
662	**--**	**--**	**PP**	**Yes**	**10197**	
661	**--**	**--**	**PP**	**Yes**	**10198**	
680	--	--	CP	No	10199	
670	**--**	**--**	**CP**	**Yes**	**10200**	

Target:	**7085-T7E01**	Date:	**12/13/2010**
Plate Number:	**330-132**	Location:	**EF 108**
Thickness, mm:	**56.52**		
Hardness, BHN:	**166**		
Obliquity:	**0°**		
Projectile:	**0.50 cal APM2**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**853 m/s**	Number of Shots:	**4**
Std Dev:	**9 m/s**	Spread:	**17 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
846	**--**	**--**	**PP**	**Yes**	**9567**	
863	**--**	**--**	**CP**	**Yes**	**9568**	
858	**--**	**--**	**CP**	**Yes**	**9569**	
846	**--**	**--**	**PP**	**Yes**	**9570**	
837	--	--	PP	No	9571	

Target:	**7085-T7E01**	Date:	**9/14/2011**
Plate Number:	**208-224**	Location:	**EF 108**
Thickness, mm:	**63.35**		
Hardness, BHN:	**174**		
Obliquity:	**0°**		
Projectile:	**0.50 cal APM2**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**907 m/s**	Number of Shots:	**6**
Std Dev:	**9 m/s**	Spread:	**21 m/s**
ZMR:	**0 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
915	**--**	**--**	**CP**	**Yes**	**10172**	
894	--	--	PP	No	10173	
918	**--**	**--**	**CP**	**Yes**	**10174**	
907	**--**	**--**	**PP**	**Yes**	**10175**	
897	**--**	**--**	**PP**	**Yes**	**10176**	
898	**--**	**--**	**PP**	**Yes**	**10177**	
907	**--**	**--**	**CP**	**Yes**	**10178**	

14.5 mm BS41

Target:	**7085-T7E01**				Date:	**9/12/2011**
Plate Number:	**208-224**				Location:	**EF 110G**
Thickness, mm:	**63.35**					
Hardness, BHN:	**174**					
Obliquity:	**0°**					
Projectile:	**14.5 mm BS41**					
X-ray or Chrono	**X-Ray**					
V_{50}:	**838 m/s**			Number of Shots:	**4**	
Std Dev:	**5 m/s**			Spread:	**10 m/s**	
ZMR:	**N/A**					
Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
832	**--**	**--**	**PP**	**Yes**	**10166**	
862	--	--	CP	No	10167	
853	--	--	CP	No	10168	
835	**--**	**--**	**PP**	**Yes**	**10169**	
842	**--**	**--**	**CP**	**Yes**	**10170**	
841	**--**	**--**	**CP**	**Yes**	**10171**	

Target:	**7085-T7E01**	Date:	**2/7/2011**
Plate Number:	**330-012**	Location:	**EF 110G**
Thickness, mm:	**74.00**		
Hardness, BHN:	**170**		
Obliquity:	**0°**		
Projectile:	**14.5 mm BS41**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**937 m/s**	Number of Shots:	**4**
Std Dev:	**5 m/s**	Spread:	**12 m/s**
ZMR:	**12 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
N/A	--	--	PP	No	13805	No X-ray
859	-1.75	1.25	PP	No	13806	
936	**-0.50**	**1.50**	**PP**	**Yes**	**13807**	
955	-1.50	1.00	CP	No	13808	
924	-0.25	0.00	PP	No	13809	
938	**0.25**	**0.50**	**CP**	**Yes**	**13810**	
942	**0.75**	**2.50**	**PP**	**Yes**	**13811**	
930	**-0.75**	**1.75**	**CP**	**Yes**	**13812**	

0.50-cal FSP

Target:	**7085-T7E01**	Date:	**3/4/2011**
Plate Number:	**330-172**	Location:	**EF 108**
Thickness, mm:	**18.57**		
Hardness, BHN:	**179**		
Obliquity:	**0°**		
Projectile:	**0.50 cal FSP**		
X-ray or Chrono	**Chrono**		

V_{50}:	**631 m/s**	Number of Shots:	**4**
Std Dev:	**9 m/s**	Spread:	**18 m/s**
ZMR:	**4 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
604	--	--	PP	No	9714	
653	--	--	CP	No	9715	
629	**--**	**--**	**PP**	**Yes**	**9716**	
650	--	--	CP	No	9717	
643	**--**	**--**	**CP**	**Yes**	**9718**	
625	**--**	**--**	**CP**	**Yes**	**9719**	
612	--	--	PP	No	9720	
625	**--**	**--**	**PP**	**Yes**	**9721**	

Target:	**7085-T7E01**	Date:	**3/14/2011**
Plate Number:	**307-433**	Location:	**EF 108**
Thickness, mm:	**25.4**		
Hardness, BHN:	**170**		
Obliquity:	**0°**		
Projectile:	**0.50 cal FSP**		
X-ray or Chrono	**Chrono**		

V_{50}:	**1061 m/s**	Number of Shots:	**10**
Std Dev:	**13 m/s**	Spread:	**39 m/s**
ZMR:	**21 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
951	--	--	PP	No	9728	
960	--	--	PP	No	9729	
981	--	--	PP	No	9730	
1004	--	--	PP	No	9731	
1070	**--**	**--**	**CP**	**Yes**	**9732**	
1041	**--**	**--**	**CP**	**Yes**	**9733**	
1057	**--**	**--**	**PP**	**Yes**	**9734**	
1021	--	--	PP	No	9735	
1042	**--**	**--**	**PP**	**Yes**	**9736**	
1084	--	--	CP	No	9737	
1077	**--**	**--**	**CP**	**Yes**	**9738**	
1042	--	--	PP	No	9739	
1066	**--**	**--**	**CP**	**Yes**	**9740**	
1056	**--**	**--**	**PP**	**Yes**	**9741**	
1062	**--**	**--**	**PP**	**Yes**	**9742**	
1039	--	--	PP	No	9743	
1055	**--**	**--**	**PP**	**Yes**	**9744**	
1089	--	--	CP	No	9745	
1095	--	--	CP	No	9746	
1080	**--**	**--**	**CP**	**Yes**	**9747**	

Target:	**7085-T7E01**	Date:	**8/31/2011**
Plate Number:	**307-433**	Location:	**EF 106**
Thickness, mm:	**25.35**		
Hardness, BHN:	**170**		
Obliquity:	**0°**		
Projectile:	**0.50 cal FSP**		
X-ray or Chrono	**Chrono**		

V_{50}:	**1026 m/s**	Number of Shots:	**4**
Std Dev:	**8 m/s**	Spread:	**18 m/s**
ZMR:	**9 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
1022	**--**	**--**	**CP**	**Yes**	**10893**	
1001	--	--	PP	No	10894	
1097	--	--	CP	No	10895	
1016	**--**	**--**	**PP**	**Yes**	**10896**	
1034	**--**	**--**	**CP**	**Yes**	**10897**	
1031	**--**	**--**	**PP**	**Yes**	**10898**	

20-mm FSP

Target:	**7085-T7E01**	Date:	**3/1/2011**
Plate Number:	**307-433**	Location:	**EF 110G**
Thickness, mm:	**25.4**		
Hardness, BHN:	**170**		
Obliquity:	**0°**		
Projectile:	**20 mm FSP**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**448 m/s**	Number of Shots:	**10**
Std Dev:	**12 m/s**	Spread:	**37 m/s**
ZMR:	**35 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
460	**0.00**	**1.50**	**CP**	**Yes**	**13831**	
423	**-0.75**	**0.00**	**CP**	**Yes**	**13832**	
405	0.25	0.50	PP	No	13833	
408	-0.25	0.00	PP	No	13834	
409	-0.25	-0.75	PP	No	13835	
436	1.25	2.50	PP	No	13836	
437	**0.25**	**0.00**	**PP**	**Yes**	**13837**	
431	0.00	0.50	PP	No	13838	
458	**--**	**--**	**PP**	**Yes**	**13839**	**By hand**
448	**0.75**	**-0.50**	**CP**	**Yes**	**13840**	
435	0.25	1.00	PP	No	13841	
437	**0.25**	**1.00**	**PP**	**Yes**	**13842**	
454	**0.50**	**1.00**	**PP**	**Yes**	**13843**	
454	**0.00**	**0.50**	**PP**	**Yes**	**13844**	
458	**0.25**	**0.00**	**CP**	**Yes**	**13845**	
454	**0.50**	**0.50**	**CP**	**Yes**	**13846**	

Target:	**7085-T7E01**	Date:	**8/15/2011**
Plate Number:	**307-433**	Location:	**EF 108**
Thickness, mm:	**25.35**		
Hardness, BHN:	**170**		
Obliquity:	**0°**		
Projectile:	**20 mm FSP**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**461 m/s**	Number of Shots:	**4**
Std Dev:	**6 m/s**	Spread:	**13 m/s**
ZMR:	**8 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
453			**PP**	**Yes**	**10122**	
482			CP	No	10123	
466			**PP**	**Yes**	**10124**	
466			**CP**	**Yes**	**10125**	
458			**CP**	**Yes**	**10126**	

Target:	**7085-T7E01**	Date:	**8/8/2011**
Plate Number:	**208-233**	Location:	**EF 108**
Thickness, mm:	**37.95**		
Hardness, BHN:	**179**		
Obliquity:	**0°**		
Projectile:	**20 mm FSP**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**835 m/s**	Number of Shots:	**4**
Std Dev:	**6 m/s**	Spread:	**12 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
831			**PP**	**Yes**	**10110**	
884			CP	No	10111	
841			**CP**	**Yes**	**10112**	
838			**CP**	**Yes**	**10113**	
829			**PP**	**Yes**	**10114**	

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Appendix B. Ballistic Test Data: 7085-T7E02

This appendix appears in its original form, without editorial change.

0.30-cal APM2

Target:	**7085-T7E02**	Date:	**2/3/2011**
Plate Number:	**371-262**	Location:	**EF 106**
Thickness, mm:	**12.62**		
Hardness, BHN:	**149**		
Obliquity:	**30°**		
Projectile:	**0.30 cal APM2**		
X-ray or Chrono	**Chrono**		

V_{50}:	**481 m/s**	Number of Shots:	**6**
Std Dev:	**8 m/s**	Spread:	**22 m/s**
ZMR:	**22 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
487	**--**	**--**	**CP**	**Yes**	**10235**	
431	--	--	PP	No	10236	
446	--	--	PP	No	10237	
466	**--**	**--**	**CP**	**Yes**	**10238**	
463	--	--	PP	No	10239	
462	--	--	PP	No	10240	
470	--	--	PP	No	10241	
478	**--**	**--**	**PP**	**Yes**	**10243**	
482	**--**	**--**	**PP**	**Yes**	**10244**	
488	**--**	**--**	**PP**	**Yes**	**10245**	
483	**--**	**--**	**CP**	**Yes**	**10246**	

Target:	**7085-T7E02**	Date:	**2/8/2011**
Plate Number:	**330-171**	Location:	**EF 106**
Thickness, mm:	**18.52**		
Hardness, BHN:	**153**		
Obliquity:	**30°**		
Projectile:	**0.30 cal APM2**		
X-ray or Chrono	**Chrono**		

V_{50}:	**614 m/s**	Number of Shots:	**4**
Std Dev:	**7 m/s**	Spread:	**14 m/s**
ZMR:	**1 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
641	--	--	CP	No	10258	
611	**--**	**--**	**PP**	**Yes**	**10259**	
624	**--**	**--**	**CP**	**Yes**	**10260**	
603	--	--	PP	No	10261	
610	**--**	**--**	**CP**	**Yes**	**10262**	
611	**--**	**--**	**PP**	**Yes**	**10263**	

Target:	**7085-T7E02**	Date:	**4/1/2011**
Plate Number:	**330-171**	Location:	**EF 108**
Thickness, mm:	**18.52**		
Hardness, BHN:	**153**		
Obliquity:	**0°**		
Projectile:	**0.30 cal APM2**		
X-ray or Chrono	**Chrono**		

V_{50}:	**567 m/s**	Number of Shots:	**6**
Std Dev:	**10 m/s**	Spread:	**26 m/s**
ZMR:	**1 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
608	--	--	CP	No	9813	
552	**--**	**--**	**PP**	**Yes**	**9814**	
600	--	--	CP	No	9815	
547	--	--	PP	No	9816	
568	**--**	**--**	**CP**	**Yes**	**9817**	
557	**--**	**--**	**PP**	**Yes**	**9818**	
543	--	--	PP	No	9819	
578	**--**	**--**	**CP**	**Yes**	**9820**	
569	**--**	**--**	**PP**	**Yes**	**9821**	
576	**--**	**--**	**CP**	**Yes**	**9822**	

Target:	**7085-T7E02**	Date:	**2/9/2011**
Plate Number:	**307-431**	Location:	**EF 106**
Thickness, mm:	**25.45**		
Hardness, BHN:	**149**		
Obliquity:	**0°**		
Projectile:	**0.30 cal APM2**		
X-ray or Chrono	**Chrono**		

V_{50}:	**664 m/s**	Number of Shots:	**6**
Std Dev:	**11 m/s**	Spread:	**24 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
654	**--**	**--**	**PP**	**Yes**	**10264**	
673	**--**	**--**	**CP**	**Yes**	**10265**	
654	**--**	**--**	**PP**	**Yes**	**10266**	
682	--	--	CP	No	10267	
653	**--**	**--**	**PP**	**Yes**	**10268**	
677	**--**	**--**	**CP**	**Yes**	**10269**	
670	**--**	**--**	**CP**	**Yes**	**10270**	

Target:	**7085-T7E02**	Date:	**7/21/2011**
Plate Number:	**618-071**	Location:	**EF 106**
Thickness, mm:	**37.97**		
Hardness, BHN:	**143**		
Obliquity:	**0°**		
Projectile:	**0.30 cal APM2**		
X-ray or Chrono	**Chrono**		

V_{50}:	**842 m/s**	Number of Shots:	**4**
Std Dev:	**6 m/s**	Spread:	**15 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
839	**--**	**--**	**PP**	**Yes**	**10776**	
863	--	--	CP	No	10777	
849	**--**	**--**	**CP**	**Yes**	**10778**	
834	**--**	**--**	**PP**	**Yes**	**10779**	
844	**--**	**--**	**CP**	**Yes**	**10780**	

0.50-cal APM2

Target:	**7085-T7E02**	Date:	**9/28/2011**
Plate Number:	**618-071**	Location:	**EF 108**
Thickness, mm:	**37.97**		
Hardness, BHN:	**143**		
Obliquity:	**0°**		
Projectile:	**0.50 cal APM2**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**635 m/s**	Number of Shots:	**4**
Std Dev:	**8 m/s**	Spread:	**15 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
612	--	--	PP	No	10201	
663	--	--	CP	No	10202	
640	**--**	**--**	**CP**	**Yes**	**10203**	
622	--	--	PP	No	10204	
627	**--**	**--**	**PP**	**Yes**	**10205**	
642	**--**	**--**	**CP**	**Yes**	**10206**	
629	**--**	**--**	**PP**	**Yes**	**10207**	

Target:	**7085-T7E02**	Date:	**12/14/2010**
Plate Number:	**330-131**	Location:	**EF 108**
Thickness, mm:	**56.31**		
Hardness, BHN:	**146**		
Obliquity:	**0°**		
Projectile:	**0.50 cal APM2**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**792 m/s**	Number of Shots:	**4**
Std Dev:	**7 m/s**	Spread:	**16 m/s**
ZMR:	**0 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
838	--	--	CP	No	9572	
812	--	--	CP	No	9573	
792	**--**	**--**	**CP**	**Yes**	**9574**	
761	--	--	PP	No	9575	
776	--	--	PP	No	9576	
784	**--**	**--**	**PP**	**Yes**	**9577**	
792	**--**	**--**	**PP**	**Yes**	**9578**	
800	**--**	**--**	**CP**	**Yes**	**9579**	

Target:	**7085-T7E02**	Date:	**9/19/2011**
Plate Number:	**618-061**	Location:	**EF 108**
Thickness, mm:	**63.6**		
Hardness, BHN:	**146**		
Obliquity:	**0°**		
Projectile:	**0.50 cal APM2**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**847 m/s**	Number of Shots:	**4**
Std Dev:	**8 m/s**	Spread:	**16 m/s**
ZMR:	**0 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
841	**--**	**--**	**PP**	**Yes**		
870	--	--	PP	No		Disregard bad yaw
906	--	--	CP	No		
890	--	--	CP	No		
880	--	--	CP	No		
873	--	--	CP	No		
864	--	--	CP	No		
856	**--**	**--**	**CP**	**Yes**		
850	**--**	**--**	**CP**	**Yes**		
829	--	--	PP	No		
838	--	--	PP	No		
840	**--**	**--**	**PP**	**Yes**		
861	--	--	CP	No		

0.50-cal FSP

Target:	**7085-T7E02**	Date:	**3/8/2011**
Plate Number:	**330-171**	Location:	**EF 108**
Thickness, mm:	**18.52**		
Hardness, BHN:	**153**		
Obliquity:	**0°**		
Projectile:	**0.50 cal FSP**		
X-ray or Chrono	**Chrono**		

V_{50}:	**573 m/s**	Number of Shots:	**4**
Std Dev:	**8 m/s**	Spread:	**18 m/s**
ZMR:	**1 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
615	--	--	CP	No	9722	
584	--	--	CP	No	9723	
564	**--**	**--**	**PP**	**Yes**	**9724**	
582	**--**	**--**	**CP**	**Yes**	**9725**	
568	**--**	**--**	**PP**	**Yes**	**9726**	
577	**--**	**--**	**CP**	**Yes**	**9727**	

Target:	**7085-T7E02**	Date:	**3/15/2011**
Plate Number:	**307-431**	Location:	**EF 108**
Thickness, mm:	**25.45**		
Hardness, BHN:	**149**		
Obliquity:	**0°**		
Projectile:	**0.50 cal FSP**		
X-ray or Chrono	**Chrono**		

V_{50}:	**957 m/s**	Number of Shots:	**4**
Std Dev:	**7 m/s**	Spread:	**14 m/s**
ZMR:	**14 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
1079	--	--	CP	No	9748	
1042	--	--	CP	No	9749	
983	--	--	CP	No	9750	
963	**--**	**--**	**PP**	**Yes**	**9751**	
949	**--**	**--**	**CP**	**Yes**	**9752**	
942	--	--	PP	No	9753	
963	**--**	**--**	**PP**	**Yes**	**9754**	
974	--	--	CP	No	9755	
967	--	--	CP	No	9756	
952	**--**	**--**	**CP**	**Yes**	**9757**	

Target:	**7085-T7E02**	Date:	**8/31/2011**
Plate Number:	**307-431**	Location:	**EF 106**
Thickness, mm:	**25.4**		
Hardness, BHN:	**143**		
Obliquity:	**0°**		
Projectile:	**0.50 cal FSP**		
X-ray or Chrono	**Chrono**		

V_{50}:	**982 m/s**	Number of Shots:	**4**
Std Dev:	**5 m/s**	Spread:	**11 m/s**
ZMR:	**N/A**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
958	--	--	PP	No	10888	
988	**--**	**--**	**CP**	**Yes**	**10889**	
977	**--**	**--**	**PP**	**Yes**	**10890**	
985	**--**	**--**	**CP**	**Yes**	**10891**	
979	**--**	**--**	**PP**	**Yes**	**10892**	

20-mm FSP

Target:	**7085-T7E02**	Date:	**2/10/2011**
Plate Number:	**307-431**	Location:	**EF 110G**
Thickness, mm:	**25.45**		
Hardness, BHN:	**149**		
Obliquity:	**0°**		
Projectile:	**20 mm FSP**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**430 m/s**	Number of Shots:	**4**
Std Dev:	**9 m/s**	Spread:	**18 m/s**
ZMR:	**18 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
348	--	--	PP	No	13813	Read by hand
378	--	--	PP	No	13814	Read by hand
489	-0.25	0.30	CP	No	13815	
--	--	--	--	No	13816	No X-ray
--	--	--	--	No	13817	No X-ray
--	--	--	--	No	13818	No X-ray
397	-0.50	1.12	PP	No	13819	
428	**0.00**	**0.25**	**CP**	**Yes**	**13820**	
407	0.75	0.90	PP	No	13821	
410	1.00	1.12	PP	No	13822	
412	-0.75	1.50	PP	No	13823	
406	0.75	1.25	PP	No	13824	
424	**1.00**	**2.02**	**PP**	**Yes**	**13825**	
396	-0.50	1.12	PP	No	13826	
411	1.00	1.03	PP	No	13827	
424	**0.75**	**0.90**	**PP**	**Yes**	**13828**	
408	-0.75	0.90	PP	No	13829	
442	**0.25**	**0.25**	**CP**	**Yes**	**13830**	

Target:	**7085-T7E02**	Date:	**8/17/2011**
Plate Number:	**307-431**	Location:	**EF 108**
Thickness, mm:	**25.4**		
Hardness, BHN:	**143**		
Obliquity:	**0°**		
Projectile:	**20 mm FSP**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**457 m/s**	Number of Shots:	**6**
Std Dev:	**8 m/s**	Spread:	**23 m/s**
ZMR:	**1 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
433			PP	No	10127	
450			**PP**	**Yes**	**10128**	
459			**PP**	**Yes**	**10129**	
486			CP	No	10130	
469			**CP**	**Yes**	**10131**	
458			**CP**	**Yes**	**10132**	
446			**PP**	**Yes**	**10133**	
460			**CP**	**Yes**	**10134**	

Target:	**7085-T7E02**	Date:	**8/4/2011**
Plate Number:	**618-071**	Location:	**EF 108**
Thickness, mm:	**37.97**		
Hardness, BHN:	**143**		
Obliquity:	**0°**		
Projectile:	**20 mm FSP**		
X-ray or Chrono	**X-Ray**		

V_{50}:	**806 m/s**	Number of Shots:	**6**
Std Dev:	**8 m/s**	Spread:	**19 m/s**
ZMR:	**7 m/s**		

Striking Velocity, m/s	Pitch (deg)	Yaw (deg)	Result, (PP/CP)	Used for V_{50}, (Yes/No)	Shot Number	Comments
794			PP	No	10103	
796			**PP**	**Yes**	**10104**	
815			**CP**	**Yes**	**10105**	
812			**CP**	**Yes**	**10106**	
812			**PP**	**Yes**	**10107**	
796			**PP**	**Yes**	**10108**	
805			**CP**	**Yes**	**10109**	

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Appendix C. Additional Ballistic Test Data

The following tables list data collected by the U.S. Army Aberdeen Test Center[1] unless otherwise noted.

Table C-1. The 0.30-cal. APM2, 30° obliquity ballistic performance.

Plate ID	Nominal Thickness		Actual Thickness		Areal Density		Ballistic Limit		Standard Deviation	
	(mm)	(in)	(mm)	(in)	(kg/m^2)	(psf)	(m/s)	(fps)	(m/s)	(fps)
7085-T7E01										
371-261	12.70	0.50	12.52	0.493	35.69	7.31	511	1677	7	23
330-172	19.05	0.75	18.52	0.729	52.77	10.81	652	2138	6	19
7085-T7E02										
330-171	19.05	0.75	18.42	0.725	52.48	10.75	608	1996	9	29

Table C-2. The 0.30-cal. APM2, 0° obliquity ballistic performance.

Plate ID	Nominal Thickness		Actual Thickness		Areal Density		Ballistic Limit		Standard Deviation	
	(mm)	(in)	(mm)	(in)	(kg/m^2)	(psf)	(m/s)	(fps)	(m/s)	(fps)
7085-T7E01										
330-172	19.05	0.75	18.52	0.729	52.77	10.81	598	1961	11	36
845885[a]	40.64	1.60	40.51	1.595	115.45	23.65	938	3077	8	26
845887[a]	50.80	2.00	52.83	2.080	150.57	30.84	1020[b]	3347[b]	—	—
7085-T7E02										
330-171	19.05	0.75	18.34	0.722	52.27	10.70	563	1848	8	25
307-432	25.40	1.00	25.45	1.002	72.53	14.86	671	2201	8	27
845886[a]	40.64	1.60	40.49	1.594	115.40	23.64	872	2861	8	26
845888[a]	50.80	2.00	52.76	2.077	150.37	30.80	993[b]	3259[b]	—	—

[a]Gooch, W. U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, unpublished data on 7085.
[b]Partial penetration at maximum projectile velocity.

[1]Gessleman, D. U.S. Army Aberdeen Test Center: Aberdeen Proving Ground, MD, unpublished data on 7085.

Table C-3. The 0.50-cal. APM2, 0° obliquity ballistic performance.

Plate ID	Nominal Thickness		Actual Thickness		Areal Density		Ballistic Limit		Standard Deviation	
	(mm)	(in)	(mm)	(in)	(kg/m^2)	(psf)	(m/s)	(fps)	(m/s)	(fps)
7085-T7E01										
330-142	50.80	2.00	50.11	1.973	142.83	29.25	782	2566	7	23
845887[a]	50.80	2.00	52.83	2.080	150.57	30.84	809	2655	10	33
330-132	50.80	2.25	56.31	2.217	160.49	32.87	843	2766	8	25
7085-T7E02										
105877	50.80	2.00	50.39	1.984	143.62	29.42	738	2423	6	21
550741	50.80	2.00	50.83	2.001	144.85	29.67	737	2418	5	16
550911	50.80	2.00	50.93	2.005	145.14	29.73	732	2403	6	21
508053	50.80	2.00	51.05	2.01	145.50	29.80	734	2408	5	18
550752	50.80	2.00	51.18	2.015	145.87	29.88	734	2407	5	17
550871	50.80	2.00	51.41	2.024	146.52	30.01	735	2413	7	24
845888[a]	50.80	2.00	52.76	2.077	150.37	30.80	753	2470	8	26
330-131	57.15	2.25	56.26	2.215	160.34	32.84	783	2568	8	25
330-011	76.2	3.00	75.31	2.965	214.64	43.96	938	3076	6	20
458531	76.2	3.00	77.47	3.05	220.79	45.22	962	3156	5	16

[a]Gooch, W. U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, unpublished data on 7085.

Table C-4. The 0.50-cal. FSP, 0° obliquity ballistic performance.

Plate ID	Nominal Thickness		Actual Thickness		Areal Density		Ballistic Limit		Standard Deviation	
	(mm)	(in)	(mm)	(in)	(kg/m^2)	(psf)	(m/s)	(fps)	(m/s)	(fps)
7085-T7E01										
330-172	19.05	0.75	18.52	0.729	52.77	10.81	568	1865	7	22
7085-T7E02										
330-171	19.05	0.75	18.36	0.723	52.34	10.72	589	1933	11	37
307-432	25.40	1.00	25.32	0.997	72.17	14.78	960	3149	5	15

Table C-5. The 20-mm FSP, 0° obliquity ballistic performance.

Plate ID	Nominal Thickness		Actual Thickness		Areal Density		Ballistic Limit		Standard Deviation	
	(mm)	(in)	(mm)	(in)	(kg/m^2)	(psf)	(m/s)	(fps)	(m/s)	(fps)
7085-T7E02										
307-432	25.40	1.00	25.43	1.001	72.46	14.84	418	1371	7	23

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G GAZONAS
RDRL WMM D
R CARTER
E CHIN
K CHO
W ROY
R SQUILLACIOTI
S WALSH
RDRL WMM E
J LASALVIA
P PATEL
RDRL WMM F
J CHINELLA
K DOHERTY
L KECSKES
J MONTGOMERY
D SNOHA

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C HUMMER
B RINGERS
RDRL WMP B
C HOPPEL
Y HUANG
M SCHEIDLER
T WEERASOORIYA
RDRL WMP C
S BILYK
T BJERKE
D CASEM
J CLAYTON
B LEAVY
D DANDEKAR
M GREENFIELD
M RAFTENBERG
S SEGLETES
RDRL WMP D
A BARD
R DONEY
M DUFFY
T HAVEL
V HERNANDEZ
S HUG
M KEELE
D KLEPONIS
H MEYER
F MURPHY
J RUNYEON
K STOFFEL
B SCOTT
W WALTERS
RDRL WMP E
P BARTKOWSKI
S BARTUS
M BURKINS
B CHAMISH
D GALLARDY (5 CPS)
W GOOCH
D HACKBARTH
E HORWATH
T JONES
C KRAUTHAUSER
B LOVE
D SHOWALTER
P SWOBODA
RDRL WMP F
N GNIAZDOWSKI
R GUPTA
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R BANTON

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T FARRAND
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S SCHRAML
R SUMMERS